

Effect of Argon Gas Injection on Acoustics Noise and Onset of Sodium Cavitation in Venturi

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ABSTRACT

The present experiment is conducted to investigate the effects of argon gas injection on the noise characteristics and onset conditions of sodium cavitation. The test section of the experiment is made of SS-316 1000 mm in length equipped with gas injector to inject argon gas into the flowing liquid sodium. We conducted the experiment at liquid sodium stagnant pressure of 0.06~0.18 MPa-a, liquid sodium temperature of 300° and 400°C, and argon gas flow rate of 0-5 cc/min. As a result, it is found that injecting argon gas into the flowing liquid sodium does not alter its noise intensity significantly (it has small effects) both for 300° and 400°C during cavitation conditions, although there is a small decrease in the noise intensity peak which might be caused by the damping of the noise by the argon gas bubbles. The onset cavitation coefficient and velocity remains relatively unchanged despite the different argon gas flow rate. During cavitation conditions, choking-like phenomena are observed in which the superficial velocities of liquid sodium remain relatively constant. In the experiment, it is observed that cavitation tends to occur at lower pressure and higher temperature. The typical spectrum of the acoustic noise intensities shows that there is an increase in the noise intensity over the range of 10~20,470 Hz when cavitation occurs in the test section with and without the injection of argon gas.

KEYWORDS

Cavitation, liquid sodium, argon gas injection, acoustics noise, onset, venturi

1. INTRODUCTION

In the development of economic sodium cooled fast reactor (SFR), reactor vessel and flow components are made compact which lead to fast flow of coolant. This fast flow of coolant might create cavitation phenomena if the local static pressure falls below its vapor pressure. Cavitation in the fluid flow system, such as pump and orifice flow meter, has been known to cause undesirable problems such as vibrations, erosion, noise and others [1, 2]. Cavitation experiments have been intensively researched by several authors in the past and the noise spectrum has been recorded well, especially in the water flow systems [3-6]. In accordance with the cavitation in water flow system, it is well known that cavitation is influenced by the

amount of the gas (air) dissolved. This dissolved gas could act as nucleation sites for the growth of cavitation bubbles when the pressure in the fluid flow system falls below a certain level (water vapor pressure) and change the onset cavitation condition. But the influence of the non-condensable gas (argon) has not been investigated in detail for liquid sodium flow system in which cavitation might occur also. This could raise a question whether the same phenomena could occur in the liquid sodium flow system or not. Therefore, in order to make clear these phenomena, the present experiment is conducted to understand the effect of the argon gas injection into the flowing liquid sodium which could act as nucleation sites for cavitation bubbles. We focus our results on the onset cavitation conditions and acoustic noise of liquid sodium flow.

2. EXPERIMENTAL APPARATUS & PROCEEDURE

2.1. Description of Liquid sodium Loop Test Apparatus

Liquid sodium cavitation experiment was conducted using a liquid sodium loop facility at Sukegawa Electric Co., Ltd. shown in Fig. 2-1. This liquid sodium loop facility can be operated up to 500°C and maximum liquid sodium flow rate of 20 L/min. It consists of a test section, an electromagnetic pump (EMP), two electromagnetic flow rate meters (EMFs), a heater, a cooler, a cold trap and an expansion tank. The heater and expansion tank control the temperature and the stagnant pressure of the liquid sodium loop at the required experimental conditions, respectively. Argon gas was used as cover gas inside the expansion tank. The flow rate of the liquid sodium was measured using the EMF at the bottom part of the loop. For the purpose of this experiment, the cold trap and EMF-2 shown by the green lines were not used.

The test section of the loop was made from SS-316. It consists of a gas injector, a venturi, a wave guide rod and a static pressure tap. A gas injector is mounted on top of the test section to inject argon gas in the flowing liquid sodium. The venturi is used to create cavitation bubbles inside the liquid sodium that passes through it. The acoustics noise signals generated from the cavitation bubbles were measured by using an accelerometer (Ono Sokki NP-2710) installed at the bottom part of the wave guide rod. The electrical signal from the accelerometer is generated when a force is applied to it. The downstream pressure of the test section was measured by using a pressure transducer (Ashcroft GC-51) connected to the pressure transducer.

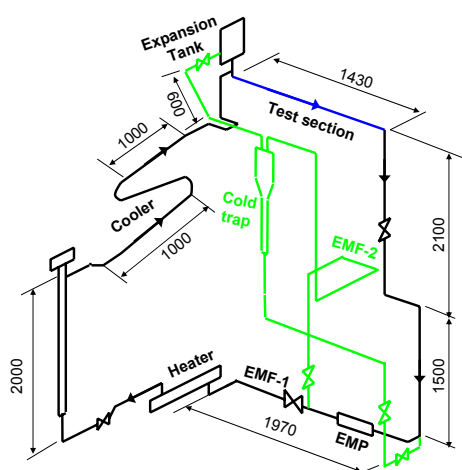


Fig. 2-1. Liquid sodium loop facility

In order to obtain the high flow rate necessary to generate cavitation conditions inside the liquid sodium, the inner diameter of the venturi is reduced to 6.5 mm with the maximum liquid sodium flow rate of 20 L/min. The pressure drops along the test section were calculated analytically to predict the required flow rate to initiate cavitation inside the venturi test section using the following formula:

$$\Delta p = (K_c + K_e) \frac{\rho}{2} V_l^2 + \frac{0.316}{Re^{0.25}} \frac{\rho}{2} V_0^2 \frac{L}{D_0} \quad (1)$$

where Δp is the pressure drop along the test section part, K_c is the contraction coefficient, K_e is the enlargement coefficient, ρ is the liquid sodium density, V_l is the liquid sodium velocity at venturi part, V_0 is the liquid sodium velocity at downstream region, Re is the Reynold's number, L is the length of the test section, and D_0 is the inner diameter of the downstream region. The equation above is derived from incompressible flow moving from point A to B along a pipe,

$$\Delta p = \rho g \left(\Delta z + f \frac{L}{D} \frac{V^2}{2g} \right) \quad (2)$$

where Δz is change in pipe elevation, f is the friction factor, L is the length of the pipe, D is the pipe diameter, and g is the gravity constant. Since the pipe was polished very smoothly, therefore it could be assumed as a smooth pipe. For smooth pipes, Blasius suggests for Reynolds's numbers between 3,000 and 100,000 [7],

$$f = \frac{0.316}{Re^{0.25}} \quad (3)$$

and for the contraction and enlargement part of the venturi, the pressure drop can be written as,

$$(K_c + K_e) \frac{\rho}{2} V^2 \quad (4)$$

From equation (2), (3) and (4) we can solve the pressure drop along the test section as indicated by equation (1).

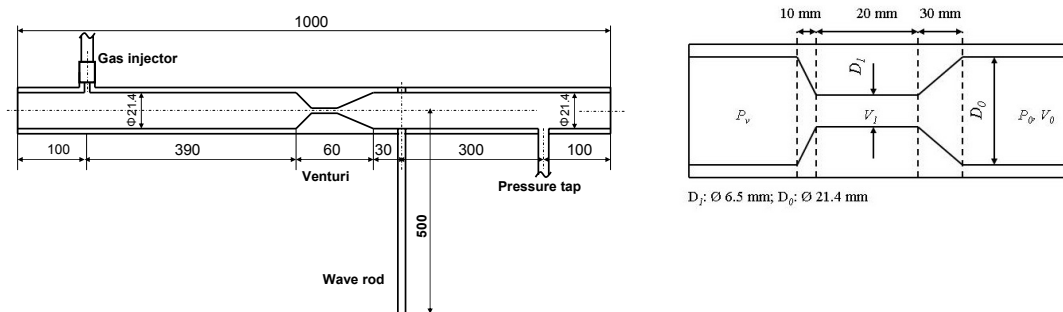


Fig. 2-2. Liquid sodium test section part (left) and venturi part of the test section (right)

2.2. Experimental Procedure

The experiment was conducted at liquid sodium stagnant pressure inside the expansion tank of 0.06~0.18 MPa-a (MPa-absolute) and temperature of 300-400°C. The detailed experimental procedures can be explained as follows:

- 1) At the beginning, the loop was circulated with a desired level of experimental temperature.
- 2) The EMP was turned off until the liquid sodium flow rate was equal to 0 l/min. Then, the pressure at the expansion tank was controlled to a desired level of experimental conditions by controlling the argon gas at the expansion tank range from 0.06~0.18 MPa-a. We define stagnant pressure as argon gas pressure in the liquid sodium loop when the flow rate of liquid sodium is equal to 0 l/min.
- 3) When the experimental conditions were all reached (temperature and pressure), the EMP was turned on again to circulate the liquid sodium inside the loop.
- 4) During circulation of liquid sodium inside the loop, argon gas was injected to the flowing liquid sodium loop starting from 0~5 cc/min using a controller through a porous tungsten plug (30% porosity). The pressure and temperature of the injected argon gas were 0.2~0.3 kgf/cm² and room temperature, respectively.
- 5) The EMP voltage was increased gradually until cavitation occurred inside of the test section and the experimental data were collected and recorded for an interval of 1 second.

Before the experiment was conducted, some components of the liquid sodium loop facility were calibrated first. The components that were calibrated are pressure transducer and electromagnetic flow rate meter (EMF). The pressure transducer (Ashcroft GC-51) was calibrated before the shipment by Nagano Keiki Co., Ltd. The calibration conditions are room temperature (24°C) using nitrogen gas (N₂). The EMF was calibrated at 200°C and 1 atmospheric pressure (1 atm). The results of the calibrated equipments can be seen on Table 2-1 and 2-2.

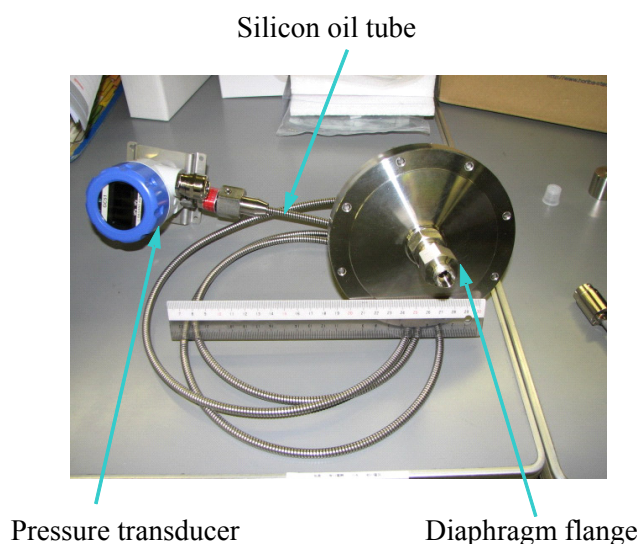


Fig. 2-3. Photograph of diaphragm type pressure gauge

The static pressure of the liquid sodium downstream was sensed by the diaphragm

connected at the pressure tap and transmitted along the silicon oil tube to the pressure transducer. This silicon oil tube also acts as a heat resistance to keep the maximum allowable temperature of the pressure gauge below 200°C, as shown in Fig. 2-3.

Table 2-1. Ashcroft GC-51 pressure transducer calibration data

Input (MPa)	Output (mA DC)
-0.100	4.00
-0.050	8.00
0.000	12.00
0.050	16.00
1.100	20.00

Table 2-2. EMF calibration data

Output (mV)	Flow rate (L/min)
0.0	6.3
0.8	7.4
2.4	10.2
3.2	12.0
4.8	16.1
5.6	18.4

Tables 2-3, 2-4 and 2-5 show the characteristic of the pressure transducer, acoustics noise sensor, and the detailed experimental conditions, respectively.

Table 2-3. Pressure transducer characteristics

Specification (pressure gauge)		Specification (diaphragm)	
Pressure range	-0.1-0.1 MPa-g	Diameter	110 mm
Output	4-20 mA	Lower flange material	SUS 316L
Maximum temperature	200°C	Upper flange material	SUS 316

Table 2-4. Sensor characteristics for liquid sodium cavitation

Sensor brand and type	Ono Sokki NP-2710	Frequency response*	fc~10kHz±5% fc~20kHz±3dB
Sensitivity (pC/m/s ²)	0.31±10%	Resonant frequency	~50kHz
Transverse sensitivity	Within 5%	Peak operating (m/s ²)	22,600
Capacitance	~340 pF	Operating temperature range (°C)	-70~+260

*fc depends on the time constant of the connected amplifier $\left(\frac{1}{2}\pi RC\right)$

Table 2-5. Experimental conditions of the cavitation test

Temperature (°C)	Stagnant pressure (MPa-a)	Ar gas injection flow rate (cc/min) at 0.2~0.3 kgf/cm ² and room temperature
300	0.06~0.18	0~5
400	0.06~0.18	0~5

3. RESULT & DISCUSSION

The results of the cavitation experiment in liquid sodium with the injection of argon gas are shown in Fig. 3-1. to 3-6. Fig. 3-1 shows the results of the noise intensity as a function of cavitation coefficient with argon gas injection from 0-5 cc/min at liquid sodium temperature of 300°C. The results show there are two different regions, the non-cavitation region (marked with the vacant symbols) and cavitation region (marked with the solid color symbols). In the cavitation region, two different cavitation conditions observed namely intermittent-cavitation and developed-cavitation. Intermittent-cavitation indicates the cavitation phenomena that occur intermittently for a few milliseconds and the noise signal fluctuated as the cavitation bubbles occur and vanish, while developed-cavitation could occur for a relatively long time (tens of seconds). The occurrence of cavitation inside the test section was judged by hearing the cavitation noise and observing the noise signal that increased suddenly (from around 30 dB rms to around 50 dB rms). The noise could be heard directly since the dimensions of the test section are relatively small and the damping of the sounds by the environment is not so large. As can be seen from Fig. 3-1, cavitation starts to occur when cavitation coefficient K is approximately 1. This condition is regarded as the onset cavitation condition. When there is no cavitation occurred in the loop, the noise intensity is relatively low (approximately below 40 dB rms). The occurrence of cavitation creates an increase in the noise intensity approximately above 40 dB rms. In the region of K below unity, there is a peak of noise intensity around the value of K 0.8~0.9 for every stagnant pressures and flow rates of the argon gas injections. It seems that after the peak has been passed, the noise intensity decreases. This phenomena probably caused by the change of cavitating zone from intermittent to developed-cavitation as observed in water fluid system [8]. The increase of the noise intensity for K above unity is caused by the micro bubbles' noise from argon gas injection into the loop. The figures show the noise intensities at developed-cavitation are relatively similar despite the fact that the stagnant pressures and the flow rates of the injected argon gas are different.

Fig. 3-2 shows the typical spectrum of the noise intensity as a function of frequency for different expansion tank stagnant pressures and argon gas injection flow rates at 300°C. The frequency data taken for the experiment ranging from 10~20,470 Hz with sampling frequency of 40,960 Hz for 1 second. At non-cavitation condition, the noise intensity is relatively constant over the entire frequency range (10~20,470 Hz), i.e. around -70 to -80 dB. The noise intensity begins to rise at intermittent-cavitation condition and becomes relatively constants at developed-cavitation condition. At 10 Hz the noise intensity is roughly around -40 dB and gradually increases to around -30 dB at 2,000~5,000 Hz. The noise then decreases again to around -60 dB at 20,470 Hz. Around 4.5 kHz, a small decrease in the noise intensity peak is observed. It might be caused by the damping of sound waves by the argon gas bubbles since bubbles will resonate in its natural frequencies subjected to pressure fluctuations as explained by Brennen [9]. Also from the figure it could be seen that the noise intensity spectrum at no-cavitation conditions increases when argon gas is injected into the test section which is caused by argon gas bubbles' noise. Generally speaking, from the Fig. 3-2 we might say that the injections of argon gas and the change of stagnant pressures has small effects (hardly

distinguishable) on the noise intensity produced by the cavitation bubbles collapses during developed-cavitation conditions.

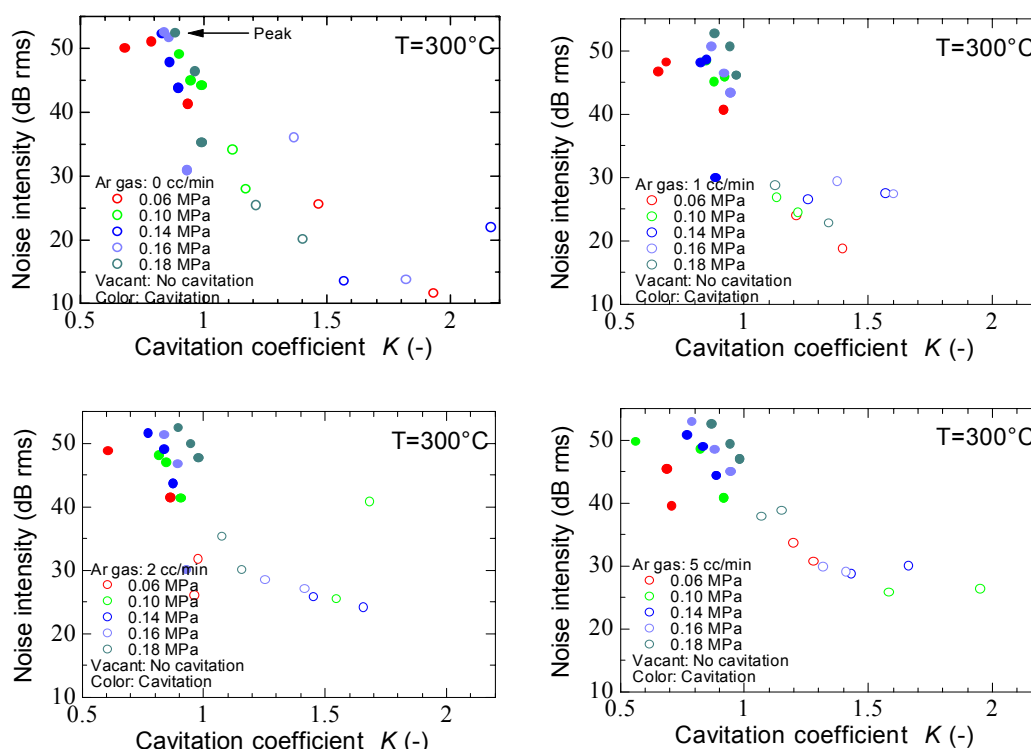


Fig. 3-1. Noise intensity as a function of cavitation coefficient at 300°C

Fig. 3-3 shows the results of liquid sodium superficial velocity in venturi as a function of liquid sodium static downstream pressures at 300°C for different expansion tank stagnant pressures ranging from 0.06~0.18 MPa-a. The figures show the different stagnant pressure conditions has a clear effect on the liquid sodium superficial velocities in the venturi. The increase of the stagnant pressures at the expansion tank increases the liquid sodium superficial velocities from around 10 m/s at 0.06 MPa-a to around 16.5 m/s at 0.18 MPa-a. The figures show also there are relatively constant velocities when the static downstream pressures decrease during cavitations (K below unity). These phenomena are similar with the choked/critical flow phenomena and might be caused by the decrease of the sound velocity in liquid sodium due to bubbles interference [10]. From this figure, it is hard to relate the effect of argon gas injection with the superficial velocity of liquid sodium since the superficial velocity does not change significantly. Roughly speaking, it has no significant effect on the relatively constant velocity conditions.

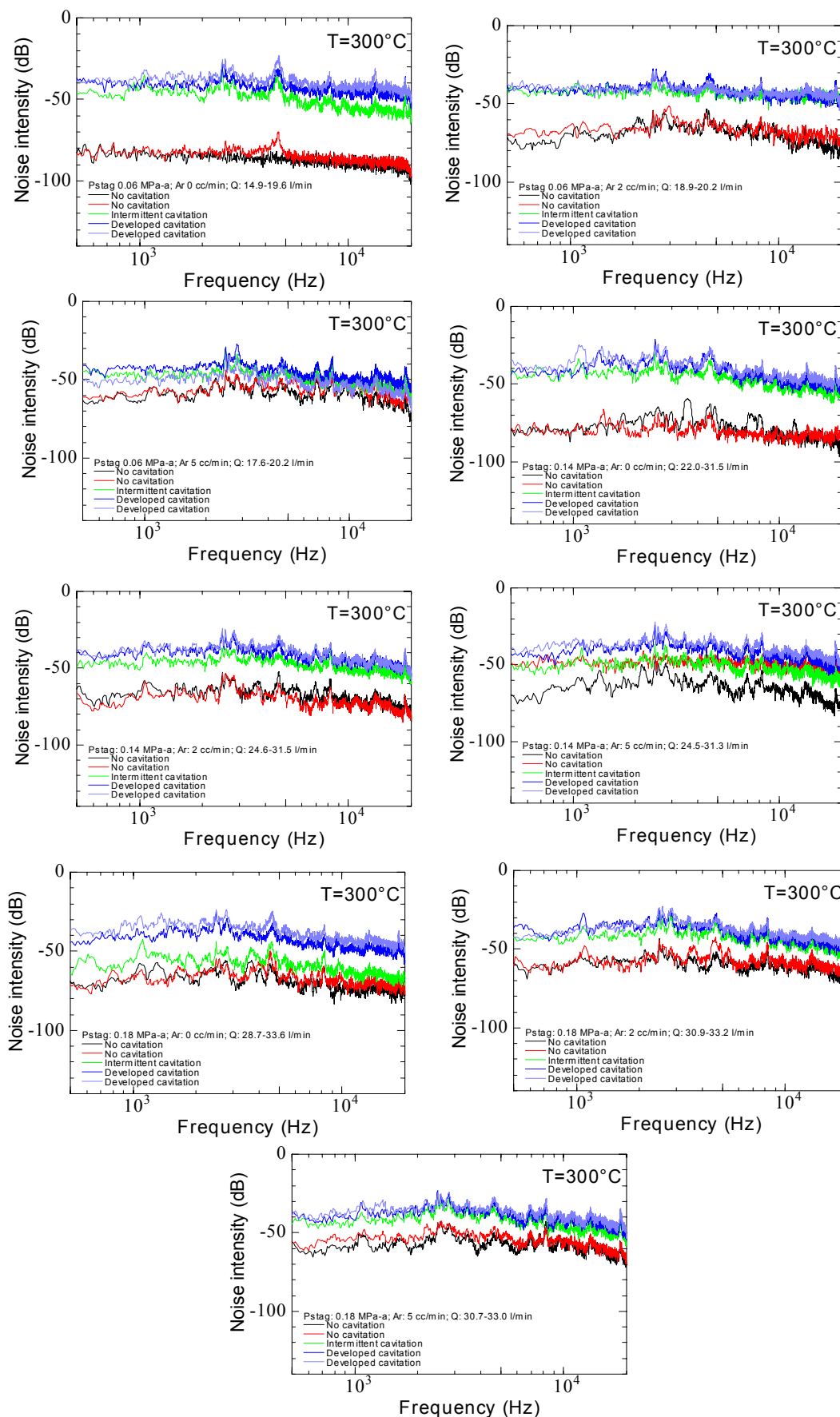


Fig. 3-2. Noise intensity as a function of frequency at 300°C

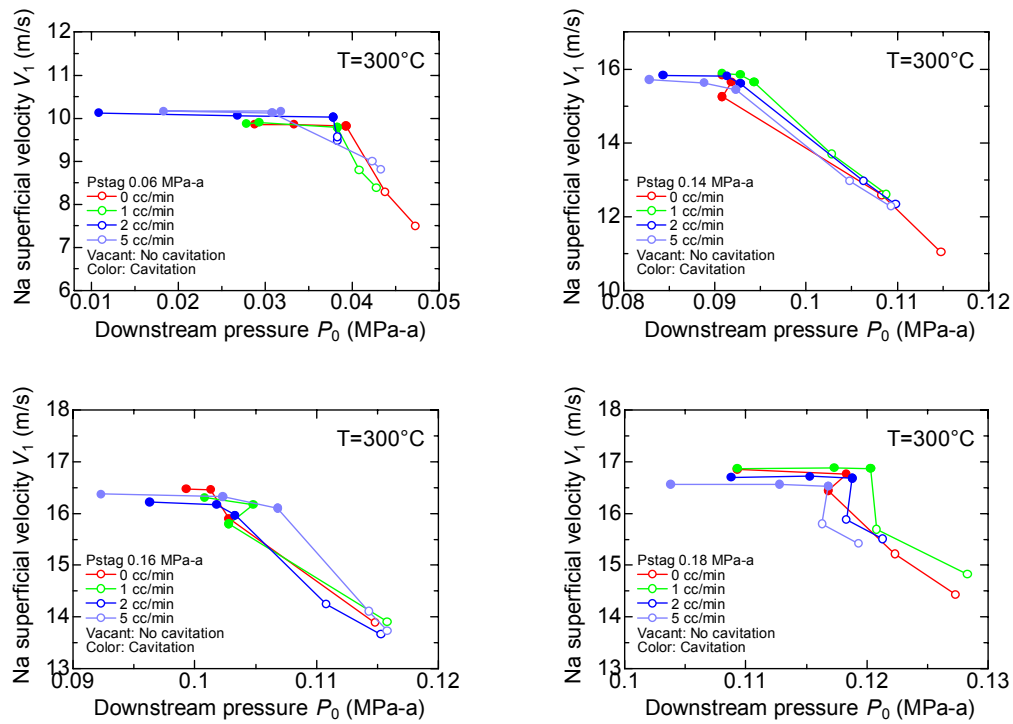


Fig. 3-3. Na superficial velocity as a function of downstream pressure at 300°C

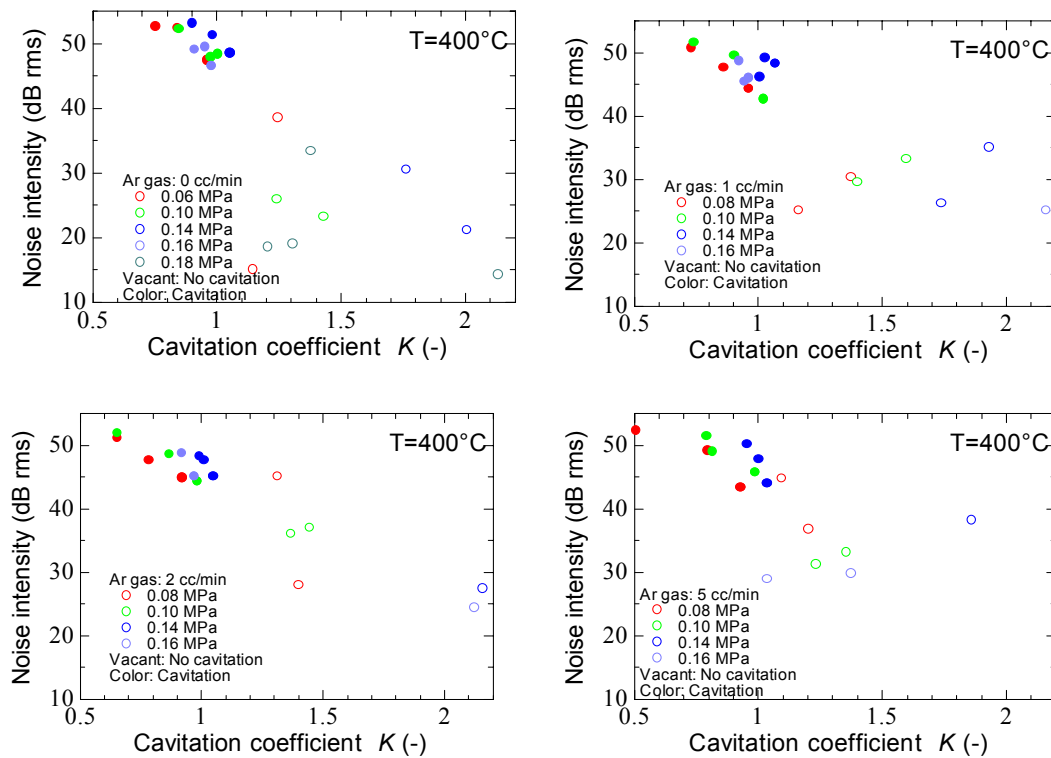


Fig. 3-4. Noise intensity as a function of cavitation coefficient at 400°C

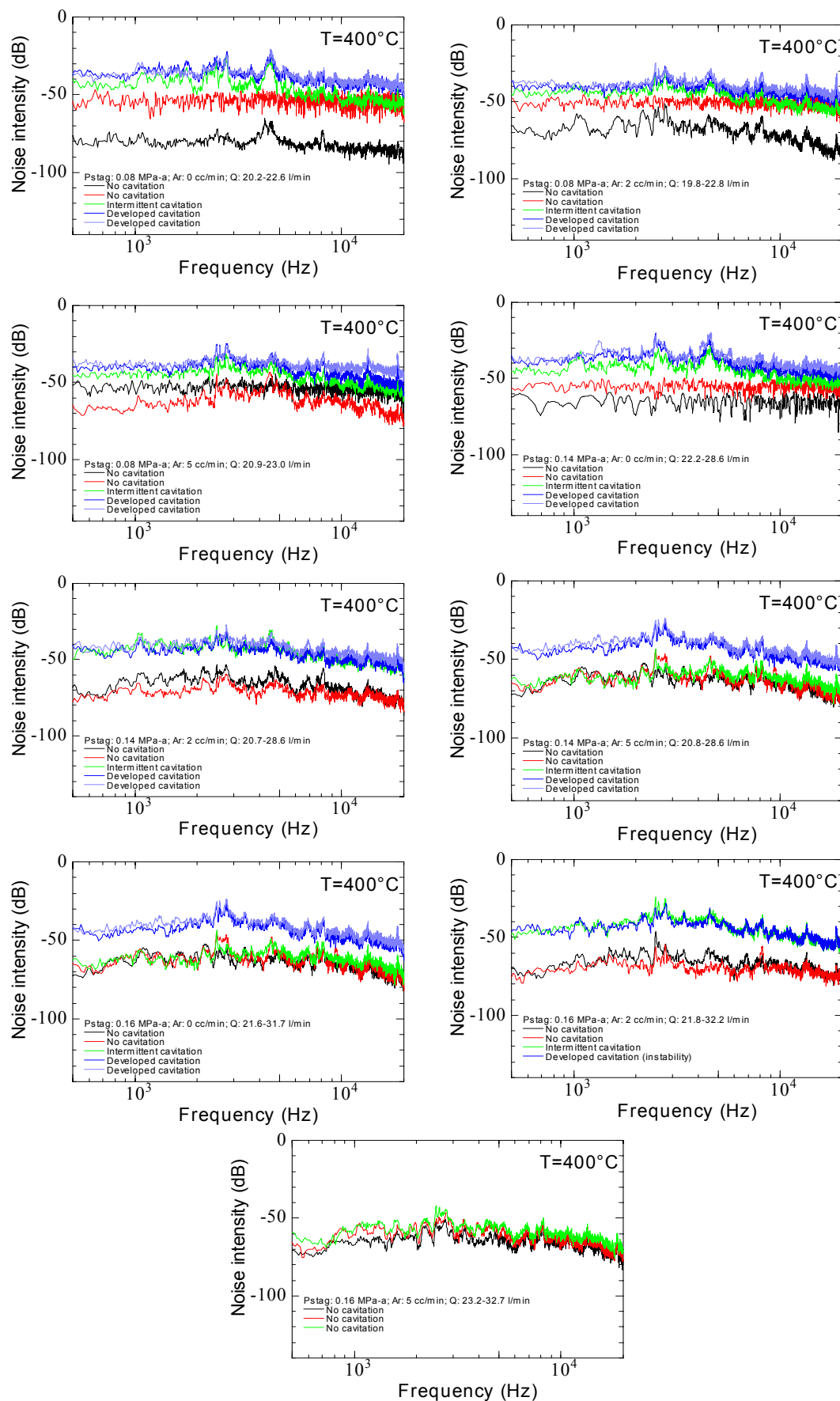


Fig. 3-5. Noise intensity as a function of frequency at 400°C

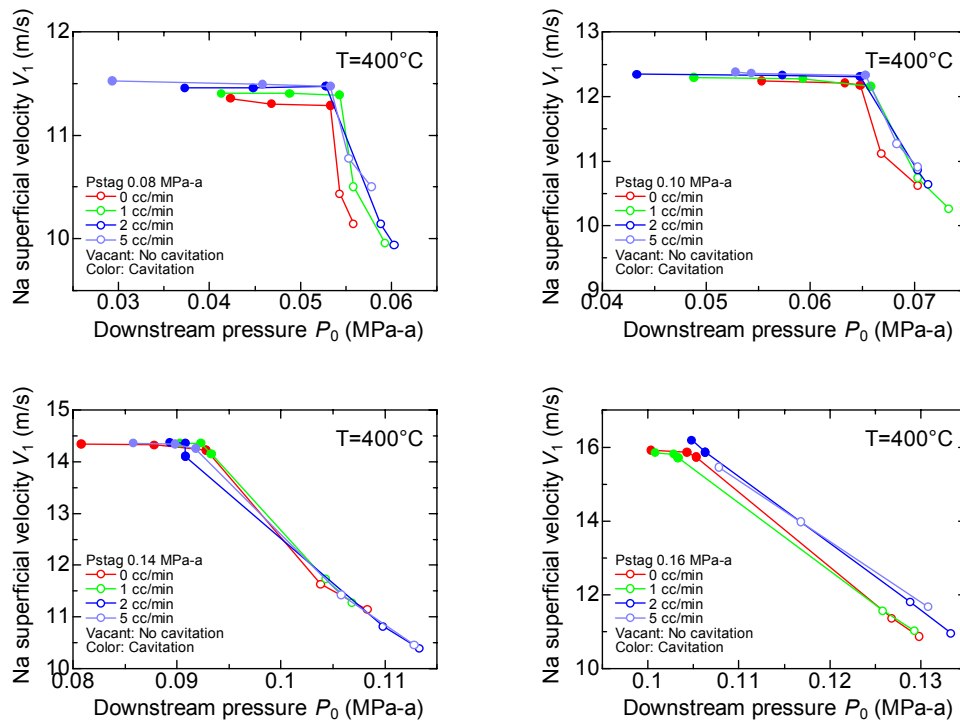


Fig. 3-6. Na superficial velocity as a function of downstream pressure at 400°C

The results of the noise intensity as a function of cavitation coefficient at 400°C , argon gas injection of 0-5 cc/min and stagnant pressure of 0.06~0.18 MPa-a are shown in Fig. 3-4. The cavitation coefficient K of the onset condition is approximately 1.1, a little bit higher than at 300°C . The results show similarity with those obtained at 300°C , but with small increase of cavitation noise above the value of K equal to unity. The recorded noises were also dispersed. This might be caused by the increase of liquid sodium vapor pressure which adds the amount of the nucleation bubbles in the fluid [11]. At 400°C , a small decrease of noise intensity peak is observed and probably caused by the increasing amount of the gas (sodium vapor and argon gas either dissolved or injected) inside the liquid sodium which damps the noise signals. This figure shows also that the noise intensity at the developed-cavitation condition becomes relatively constant with the magnitude of around 50 dB rms.

In Fig. 3-5, the results show that the noise intensity as a function of frequency at 400°C also have similarities with the results at 300°C in which the noise intensities gradually increase from around -40 dB at 10 Hz to around -30 dB at 2,000~5,000 Hz and then decreases again to around -60 dB at 20,470 Hz, except at 0.16 MPa-a and argon gas flow rate of 5 cc/min in which there are no occurrences of cavitation (the maximum voltage level of EMP). This condition might be caused by the accumulation (dissolved) of argon gas in the loop since the injected argon gas from the previous experiment at the same stagnant pressure and temperature was not removed, therefore the loop system pressure increases. Since cavitation is not easily occur at higher pressure, higher EMP's voltage is required to keep the desired level of flow rate for cavitation inception condition. Also as can be seen in Fig. 3-5, at 0.16 MPa-a and argon gas injection flow rate of 2 cc/min there is an instability of the noise intensity observed in the developed-cavitation. The noise intensity increases and decreases randomly for a few seconds. At present, this instability phenomena remain unsolved. The small decrease of the noise intensity at 4.5 kHz is also observed as in 300°C .

Fig. 3-6 shows the results of liquid sodium superficial velocity as a function of downstream

static pressure obtained at 400°C. The results obtained at 400°C show the similar trends as those obtained at 300°C (Fig. 3-3). At 0.08 MPa-a, the relatively constant liquid sodium superficial velocity in the venturi is around 11.5 m/s. The velocity then increases to around 14.5 and 16 m/s at 0.14 MPa-a and 0.16 MPa-a, respectively. At the same stagnant pressure (0.14 MPa-a), the superficial velocity at 400°C is a little bit lower than that at 300°C, which indicates that at higher temperature, cavitation tends to occur more easily. Again, as observed at 300°C, the injection of the argon gas in the flowing liquid sodium loop at 400°C has no significant effect on the liquid sodium superficial velocity at 0.08, 0.14 and 0.16 MPa-a, respectively.

The small effects of the argon gas injections into the flowing liquid sodium loop might be explained in this way. During the operation of the liquid sodium loop, the velocity of the liquid sodium is very high. This high velocity is needed in order to create a very low static pressure along the venturi tube. The cavitation bubbles start to form at the throat of the venturi test section when the static pressure is less than the vapor pressure of the liquid sodium at some point of experimental temperature. The argon gas bubbles formed by the injection of argon gas into the high velocity liquid sodium loop would change in shapes and sizes when they grow, pass through the venturi and collapse at the downstream region due to pressure gradients, boundary layers, separation, reentrant jet and turbulence. The change of bubbles' sizes and shapes into smaller ones would reduce the noise intensity during the collapse conditions at the downstream region. Furthermore, smaller cavitation bubbles would create mute cavitation noise when they collapse due to attenuation by the fluid and the wall; hence the noise intensity remains relatively unchanged. Chocking-like phenomena that occurred during cavitation conditions could also restrict the amount of nuclei sites (bubbles) in the liquid sodium from entering the venturi part, growing and collapse downstream. Therefore, the noise intensity is almost unchanged.

4. CONCLUSION

Liquid sodium cavitation experiment in the venturi with the injection of argon gas has been performed and some conclusions could be drawn, i.e.

- 1) Argon gas injection creates an increase of the noise intensity at non-cavitation region. The noise intensity peak at cavitation region decreases a little with the effect of argon gas injection.
- 2) The onset cavitation coefficient remains relatively unchanged despite the different argon gas flow rate.
- 3) A reduce of the noise intensity at 4.5 kHz is observed which might be caused by the damping of sound wave by the argon gas bubbles.
- 4) The occurrence of cavitations creates an increase of the noise intensity over the range of 10~20,470 Hz both at 300° and 400°C with and without the injection of argon gas.
- 5) The choking-like phenomena is observed when cavitation occurs in the venturi test section with and without the injection of argon gas.
- 6) The onset superficial velocity for cavitation is affected by the stagnant pressure and temperature, and not by the argon gas flow rate. The higher the stagnant pressure, the higher the onset velocity to start cavitation in the venturi. The increase of the liquid sodium temperature from 300° to 400°C tends to make cavitation phenomena occur more easily at the same stagnant pressure.
- 7) The injection of argon gas in the flowing liquid sodium loop does not change the noise intensity created by the collapse of the cavitation bubbles at 300° and 400°C significantly (it has small effects), although there is a small decrease in the noise intensity peak which might be caused by the damping of the noise by the argon gas bubbles. This finding might be caused

by the choking of the liquid sodium flow, and the change in sizes and shapes of the argon gas bubbles when pass through the venturi and collapse downstream.

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REFERENCES

1. Stanley G. Young, James R. Johnston, "Effect of Cover Gas Pressures on Accelerated Cavitation Damage in Sodium", *NASA TN D-4235*, November, (1967).
2. Kale, R. D. and M. Rajan, "Developments in Sodium Technology", *Current Science*, **Vol. 86**, No. 5, March 10, (2004).
3. P. Testud, P. Mussou, A. Hirschberg, Y. Auregan, "Noise Generated by Single-Hole and Multi-Hole Orifices in A Water Pipe", *Journal of Fluid and Structures* **23**, pp. 163-189, (2007).
4. Timo Koivula, "On Cavitation in Fluid Power", *Proceeding of 1st FPNI-PhD Symposium*, Hamburg, pp. 371-382, (2000).
5. P. Courbiere, "An acoustic Method for Characterizing The Onset of Cavitation in Nozzles and Pumps", *International Symposium on Cavitation Inception*, pp. 137-143, (1984).
6. S. R. Bistafa, "Noise Generated by Cavitation in Orifice-Plates with Some Gaseous Effects", *International Symposium on Cavitation and Multiphase Flow Noise*, pp. 41-52, (1986).
7. Giles, R. V., J. B. Evett, C. Liu, *Schaum's Theory and Problems, Fluid Mechanics and Hydraulics*, 3rd Edition, McGraw-Hill, Inc. (1994).
8. Sato, K. and Saito, Y., "Unstable Cavitation Behavior in a Circular-Cylindrical Orifice Flow", *JSME Int. Journal, Series B*, **Vol. 45**, No. 3, pp. 638-645, (2002)
9. Brennen, C. E., *Cavitation and Bubble Dynamics*, Oxford University Press, Inc., (1995).
10. Ardiansyah, T. *et al*, "Acoustic Noise and Onset of Sodium Cavitation in Venturi", *NTHAS6*, Okinawa, Japan, November 24-27, (2008).
11. Gouin, H. and Espanet, L. "Bubble Number in a Cavitating Flow", *C. R. Acad. Sci. Paris, t. 328, IIb*, pp. 151-157, (2000).